REGIONS OF THE BRAIN IMPORTANT FOR VISION

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CHAPTER CONTENTS

INTRODUCTION

Following the initial processing of visual information within the retina, information is carried to higher brain centres for intermediate and higher order processing. Approximately 40% of the brain is devoted to processing of different aspects of vision. How basic visual information is passed to the primary visual cortex, this is called the visual pathway, will be considered first.Then, the manner how information is passed from the primary visual cortex to higher cortical regions for advanced stages of visual processing will be studied.

OPTIC NERVE

All visual information is carried by the axons of ganglion cells down the optic nerve to synapse in higher brain areas. With respect to the visual pathway, ganglion cell axons synapse within the lateral geniculate nucleus (LGN) of the thalamus.

The total length of the optic nerve is around 5cm and it has different names depending its location. The portion that lies within the orbit is termed the *intraorbital* optic nerve and is approximately 25mm long.The *optic nerve head* is that portion that lies within the scleral canal of the eyeball. It is located 15 degrees nasal to the macula and slightly above. No rods or cones are present at the nerve head which thus constitutes a *blindspot*. The nerve passes to the rear of the orbit and enters the optic canal in the sphenoid bone along with the ophthalmic artery. The nerve portion within the optic canal is termed the *intracanalicular* portion and extends for about 5mm. It then enters the subarachnoid space and progresses towards optic chiasm as the *intracranial* portion of the optic nerve.

PATHWAY TO LATERAL GENICULATE NUCLEUS

The optic nerve fibres (retinal ganglion cell axons) become myelinated upon leaving the lamina cribrosa and send action potentials along the optic nerve towards the brain.

On entering the cranium, the optic nerves meet at the *optic chiasm (chiasm means cross)*. Here the fibres from the *nasal* retina cross over to the contralateral *optic tract* while the *temporal* fibres remain on the same side (ipsilateral) (Figure 9.1). A portion of the nasal fibres extend forwards slightly before heading backwards, forming a feature called the *Anterior Knee of Wilbrand*.

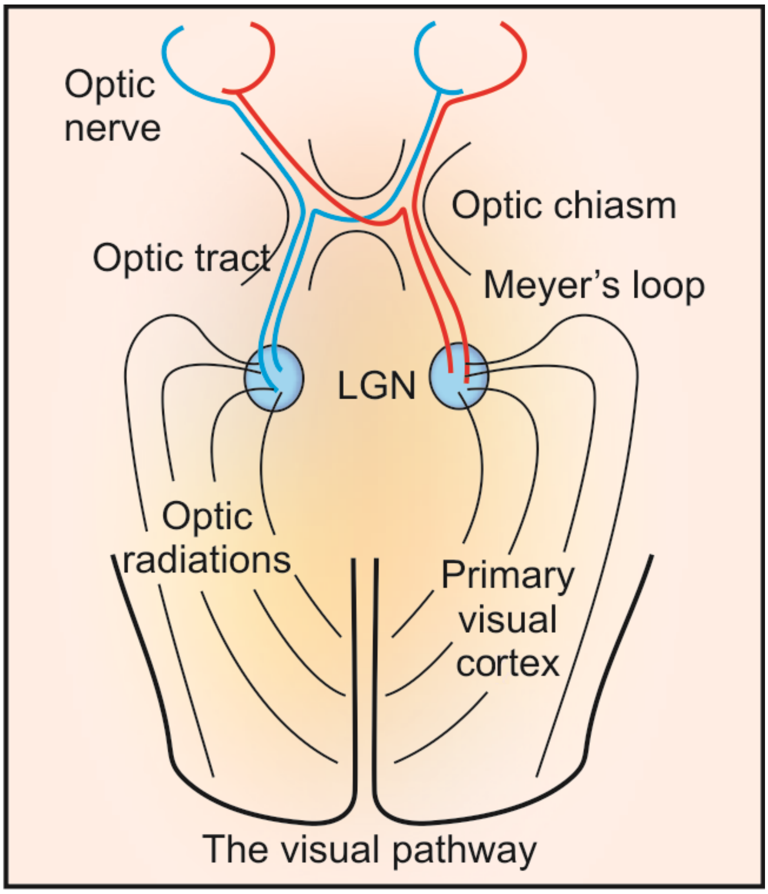

Figure 9.1: *Pathway of fibres crossing optic chiasm*

Similar to the optic nerve, the optic chiasm is surrounded by the meningeal sheaths and cerebrospinal fluid.

The optic tracts diverge from the chiasm and run around the outside of the brainstem until they meet the *lateral geniculate nucleus* (LGN). Afferent fibres mediating the pupillary light reflex leave the optic tract slightly before the LGN and head to the superior collliculus of the tectum in the midbrain (Figure 9.2).

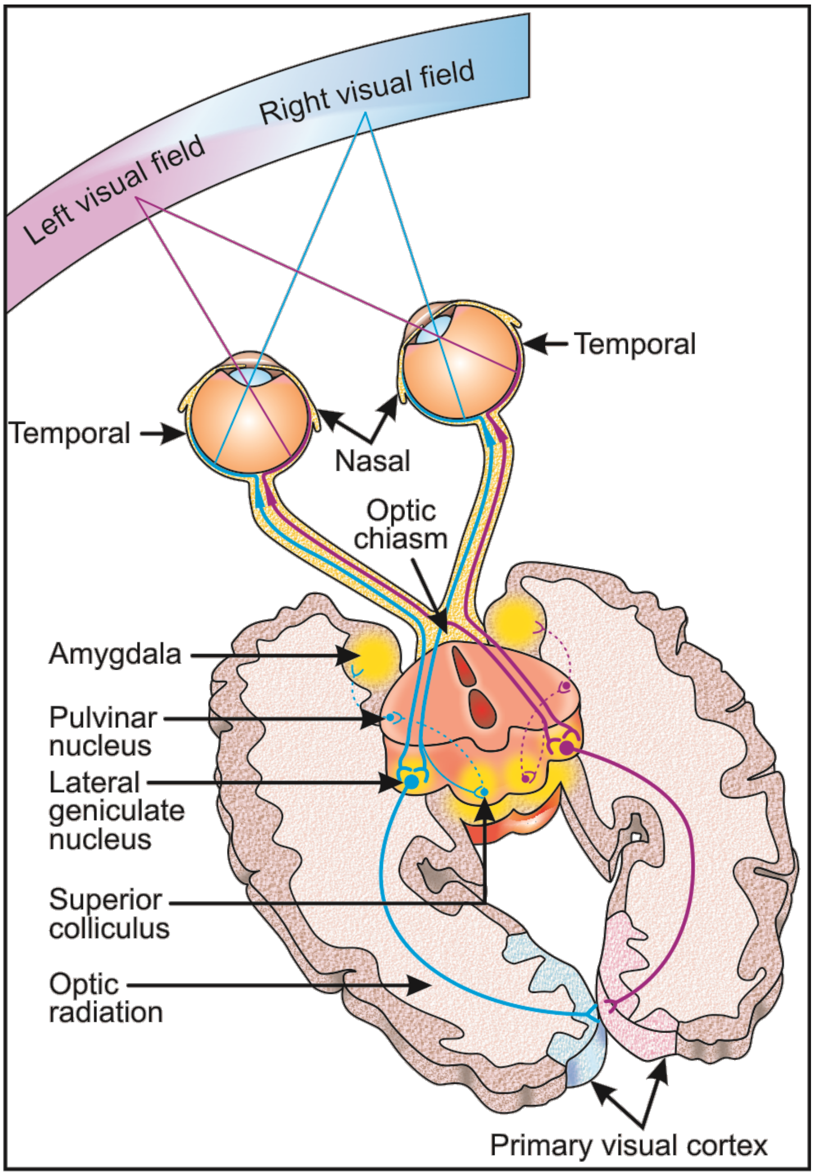

Figure 9.2: *Brachium of fibres carrying pupillary light reflex leaves optic tract before LGN to synapse in superior colliculus.*

LATERAL GENICULATE NUCLEUS (LGN)

The thalamus (means inner chamber) is a large “relay” station, situated on the wall of the third ventrical between the cerebral cortex and midbrain. This is where the majority of ganglion cell axons synapse.

The LGN (Figure 9.3) contains 6 main layers with thinner ones in between, the layers stacking on top of one another like a pile of pancakes. Of the main layers, 1 and 2, the two most dorsal layers, contain larger cells than the other four layers and are thus termed the *magnocellular* layers. The other four layers are referred to as the *parvocellular* layers. Ganglion cells which project to these different layers are thus termed magnocellular or parvocellular also. Smaller layers in between the major layers contain small nuclei and are termed the *koniocellular* layers.

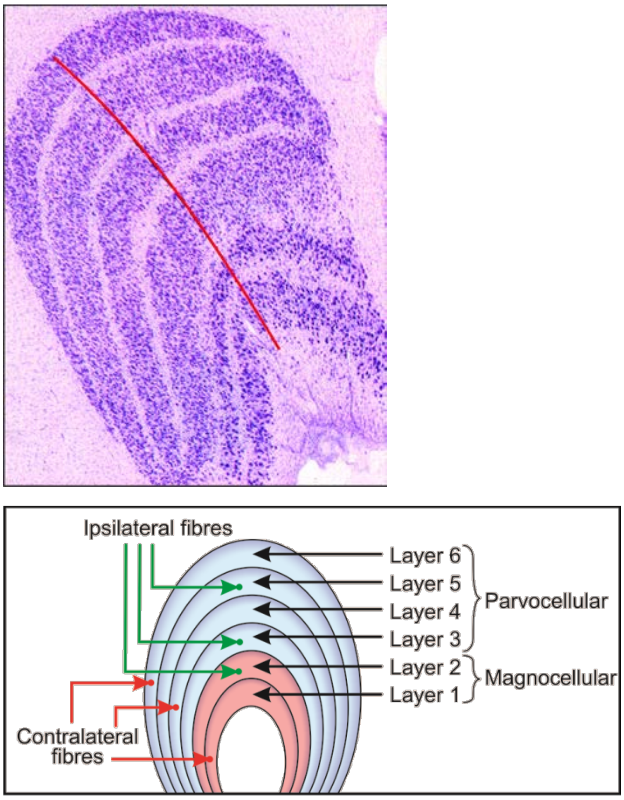

Figure 9.3: *The six-layered lateral geniculate nucleus*

The magnocellular layers receive input mainly from the larger *parasol* ganglion cells that carry achromatic information and respond maximally to stimuli of high temporal frequency and low contrast. The parvocellular layers mainly receive input from the midget ganglion cells that display red/green colour opponency, high spatial acuity and medium temporal resolution.

The thinner koniocellular layers receive input from the small bistratified ganglion cells that display blue/yellow opponency and low spatial and temporal resolution.

Each of the main LGN layers receives input from only one eye (R or L) as follows (Figure 9.4):

Magnocellular:

Layer 1: contralateral eye

Layer 2: ipsilateral eye

Parvocellular:

Layer 3: ipsilateral eye

Layer 4: contralateral eye

Layer 5: ipsilateral eye

Layer 6: contralateral eye

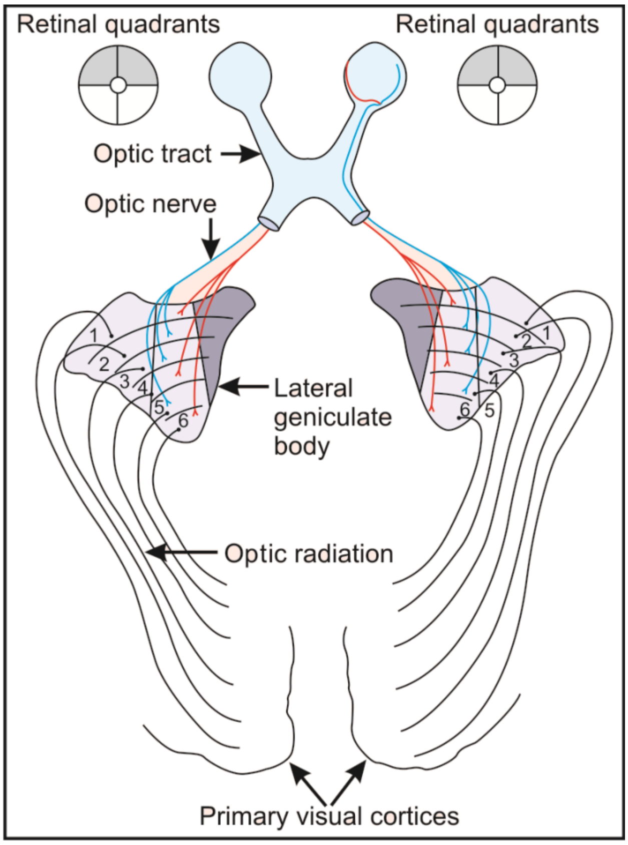

Figure 9.4: *Diagram showing retinal projections to different LGN layers. Each layer receives input from only one eye; Macular fibres project to central posterior nucleus*

Unlike in the retina, where cells display decreasing density with eccentricity, the cells in the LGN are fairly evenly spaced. Projection from the retina to the LGN approximates a 'polar to cartesian' transformation (Figure 9.5). The visual signal then leaves the LGN via the *optic radiations*.

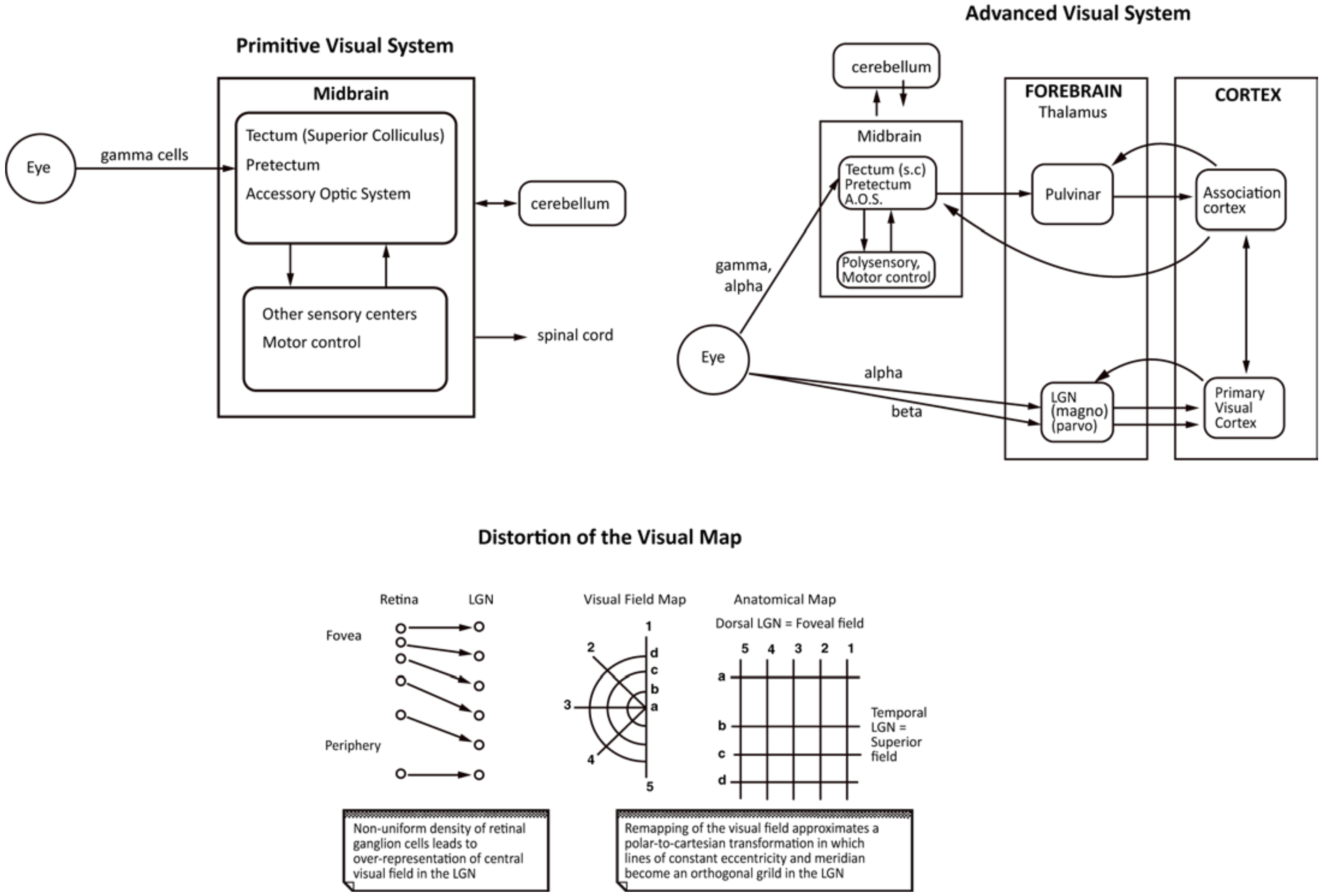

Figure 9.5: *Schematic of Projections from eye to different brain regions*

OPTIC RADIATIONS

The optic radiations are a large white matter tract that contain the axons of the LGN neurons as they pass to the primary visual cortex. They spread out like a fan upon leaving the LGN (Figure 9.6).

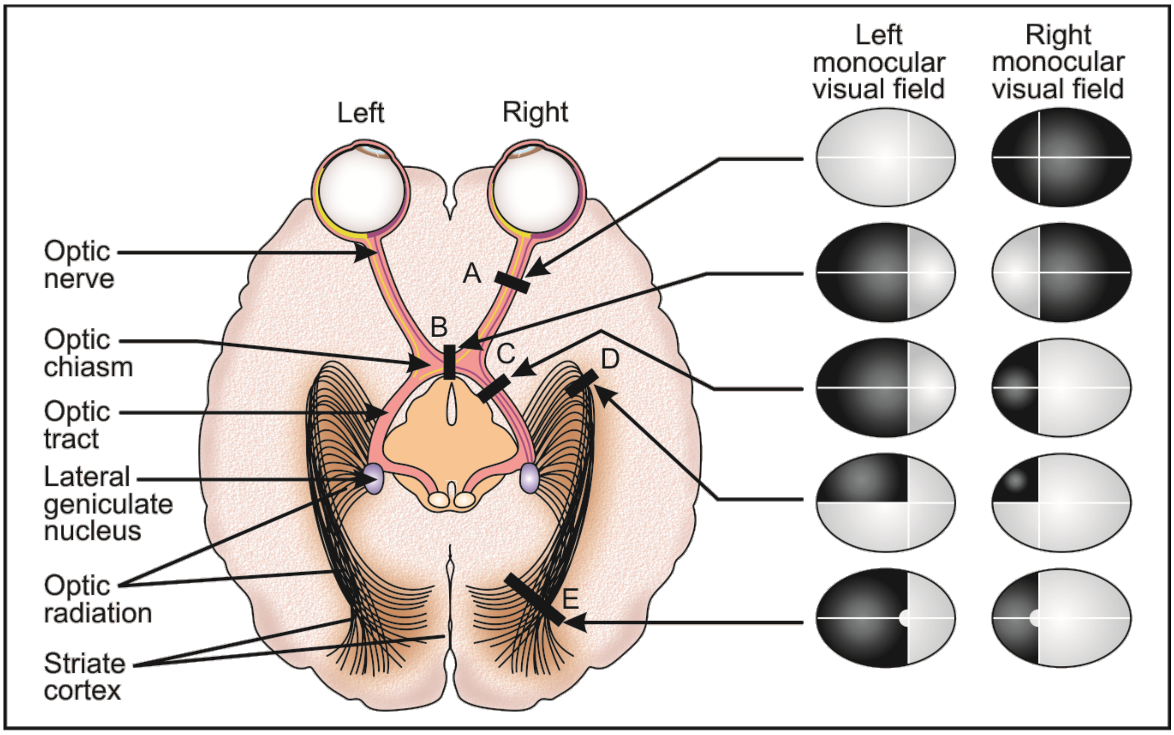

Figure 9.6: *The primary visual pathway from below, showing the pattern of visual loss associated with lesions at different points in the pathway*

Inferior fibres, carrying information from the superior visual field loop forwards, around the lateral ventricle, forming *Meyer's Loop* before heading backwards within the white matter of the cortex. Damage in the region of Meyer's loop thus leads to superior field defects (see lesion at location 'D' in Figure 9.6).

Superior fibres take a straighter path through the temporal lobe before synapsing in the *primary visual cortex* (V1).

PRIMARY VISUAL CORTEX

The *primary visual cortex* is located on each of the banks of the calcarine fissure within the occipital lobe (Figure 9.7). The primary visual area is also known as Brodman's area 17, the Striate cortex and Visual Area 1 (V1).

Forming the first point of entry of visual information to the cortex, it displays a 6-layered cross sectional structure (hence 'striate') (Figure 9.7).

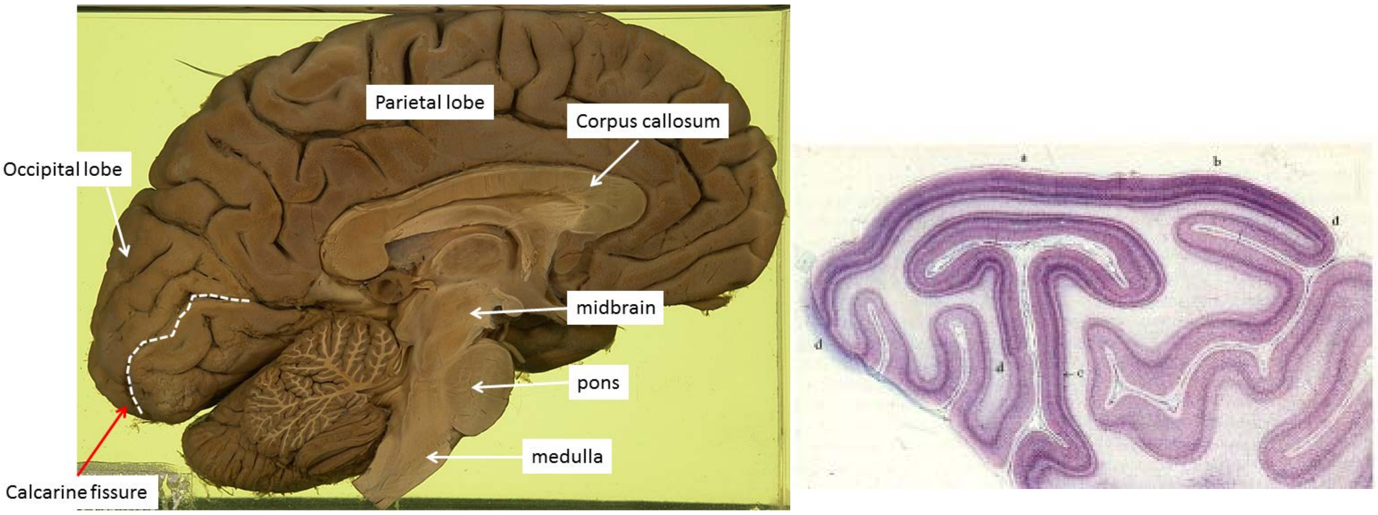

Figure 9.7: *Medial view of the hemisphere showing the calcarine fissure. Cross section through V1 ("striate" cortex)*

Layer 4C is the main input layer and contains *stellate cells* (star-shaped) (Figure 9.8a). Magnocellular input is to 4Ca and parvocellular input is to 4A and 4Cb.

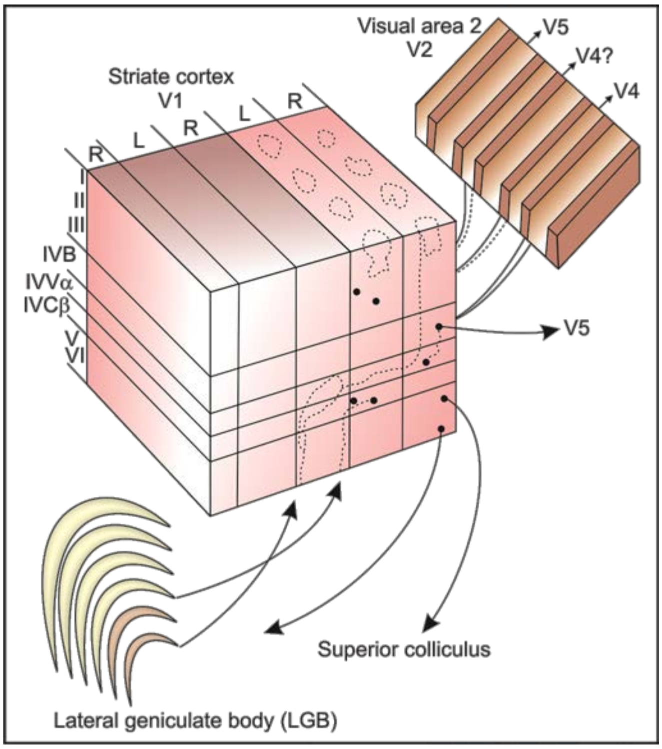

Figure 9.8(a): *Projections from LGN to different layers of V1*

Communication occurs between layers within V1, e.g. 4C to layer 3, and between layers 2 and 3. Layer 4B and the upper layers (2 and 3) send their main output to other cortical areas. Lower layers (5 and 6) send output mainly to deeper brain structures (e.g. superior colliculus) and contain triangular shaped *pyramidal cells* (Figure 9.8b).

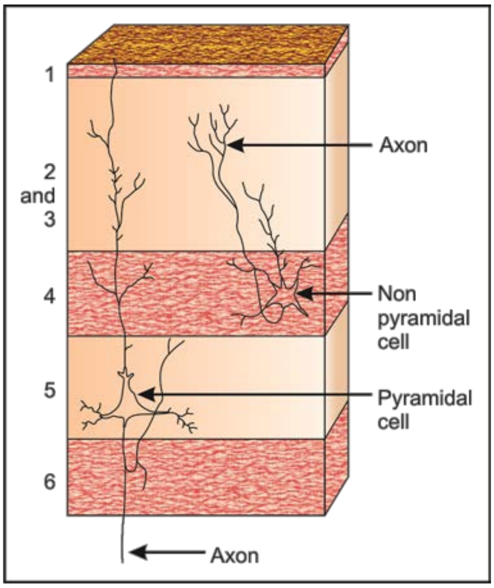

Figure 9.8(b): *Main input layer (4) contains stellate non-pyramidal cells; main output Layers (5 and 6) contain mainly pyramidal cells*

Vertical 'columns' in V1 represent different ocular dominance and stimulus orientation selectivity. These different column types extend across V1 in orthogonal directions and run all the way through the depth of the cortex (Figure 9.9a).

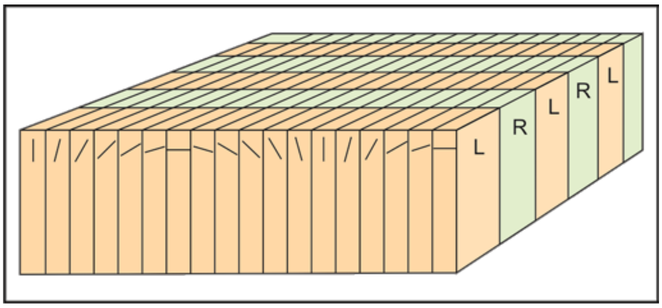

Figure 9.9 (a): *Ocular dominance and orientation columns in V1. Over approximately 1mm horizontal distance, either orientation selectivity changes through 90 degrees or ocular dominance from R to L eye*

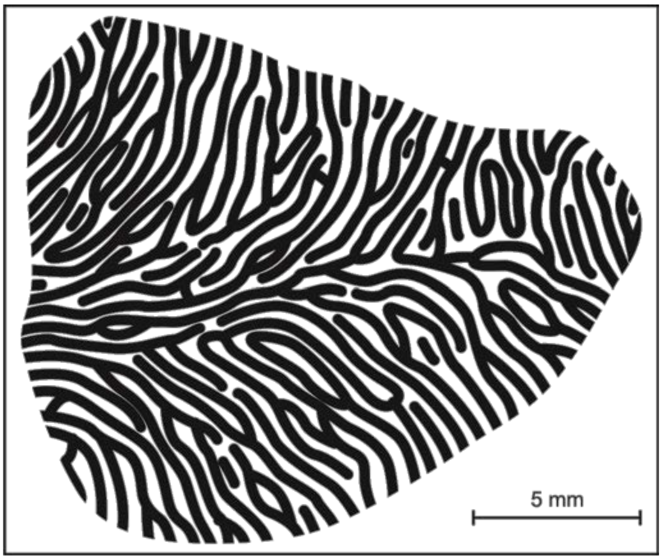

Figure 9.9 (b): *Labelled ocular dominance columns*

The fovea is represented on the most posterior part of V1 on a region sometimes referred to as the macular cortex. The peripheral visual field is represented deeper inside (Figure 9.10). The calcarine sulcus divides the superior and inferior fibres (superior and inferior field).

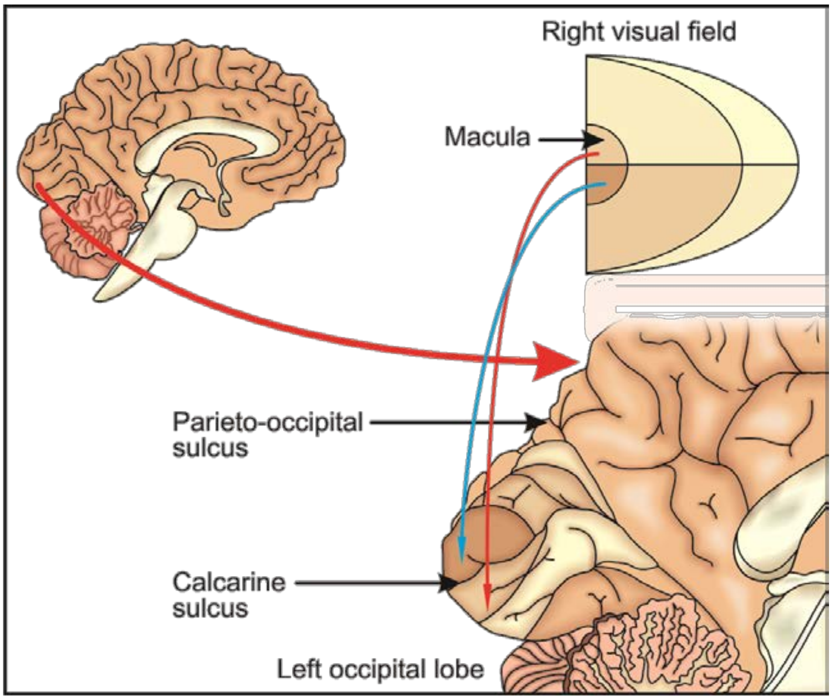

Figure 9.10: *Representation of different field locations on V1*

EXTRASTRIATE AREAS IMPORTANT FOR VISION

Around 40% of the cortex is involved in processing of visual information. From the primary visual cortex, information is carried to a variety of locations within the brain that process information. Higher processing of vision is broadly divided into the “where” and “what” pathways, corresponding to information processing where an object is within the visual field, or visual processing that identified what the object is that is being viewed.

The where pathway is also referred to as the dorsal pathway and involves information derived mostly from the magnocellular pathway being passed from V1 to V2, V3 to area MT, a region in the mid temporal lobe. Area MT has a columnar organization like V1, however neurons in this region of the brain have very large receptive fields that respond particularly to moving stimuli. Thus, area MT is recognized as being a crucial brain region for processing motion.

The “what” pathway is also referred to as the ventral pathway. This pathway provides information about what an object is. It involves information processing from V1, V2 V3, V4 and area IT, an area in the inferior temporal lobe, which is particularly important for recognizing objects and faces.

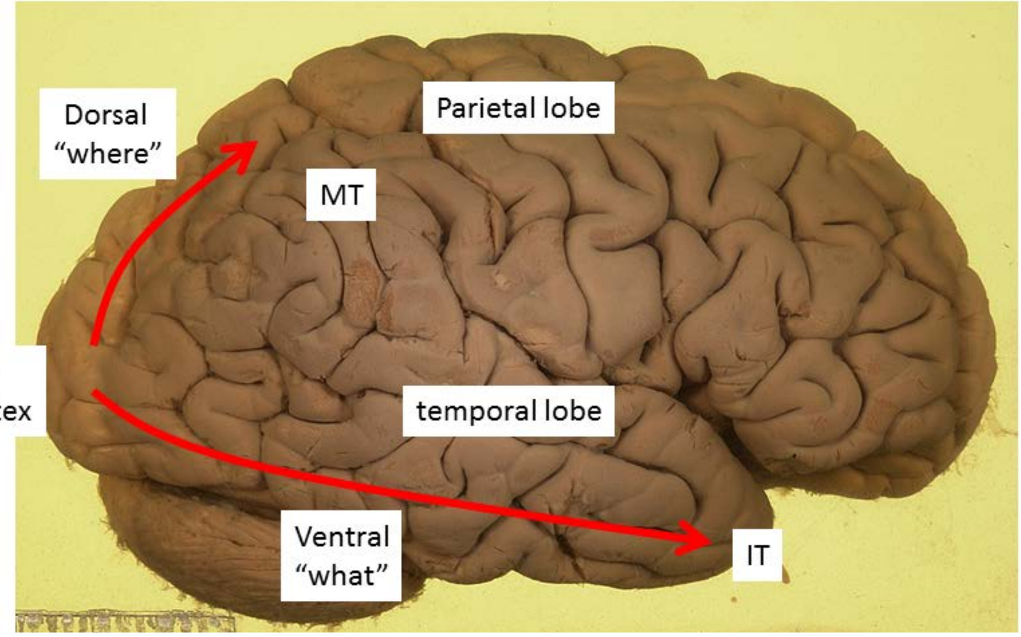

Figure 9.11. *Hemisphere of the brain showing the dorsal and ventral pathways*

BLOOD SUPPLY TO THE REGIONS OF THE BRAIN IMPORTANT FOR VISION

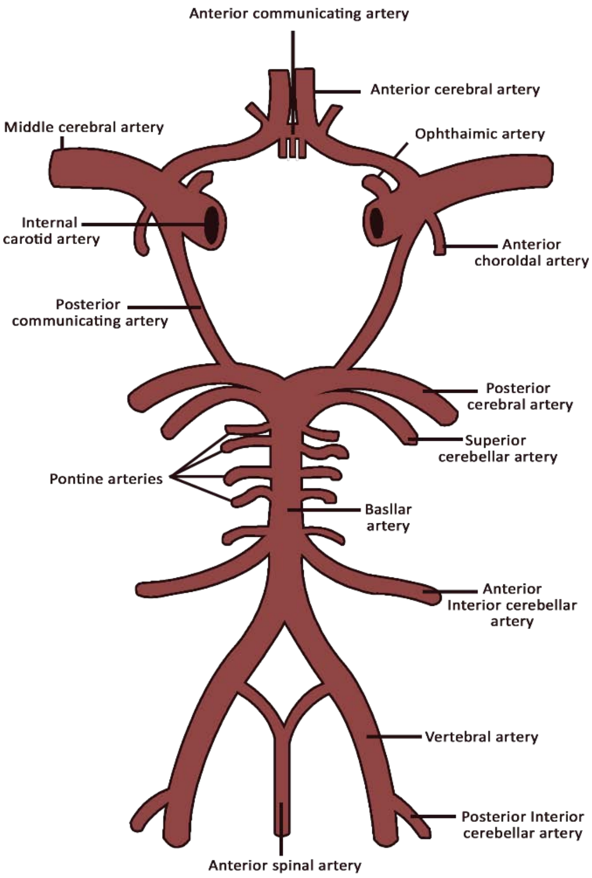

Figure 9.12: *The circle of Willis Image inspired by http://en.wikipedia.org/wiki/File:Circle_of_Willis_en.svg*

Arterial supply to the brain is via the anastamosis of vascular supply from the internal carotid arteries and the vertebral arteries posteriorly. Thus, the brain receives a dual blood supply. These two vascular systems meet at the Circle of Willis, a ring of vessels located at the base of the brain, near the optic chiasm.

As shown in Figure 9.12, the two vertebral arteries form the basilar artery that runs rostrally along the surface of the pons. The basilar artery bifurcates to form the two posterior cerebral arteries. These two arteries supply the occipital lobes.

The anterior supply of the brain is provided by the internal carotid arteries which bifurcates to form the middle cerebral artery and anterior cerebral arteries. There is a small anterior communicating artery that provides blood flow between the two anterior cerebral arteries. In addition, the posterior communicating arteries form a connection between the internal carotid and the posterior cerebral arteries.

As shown in Figure 9.13, the posterior cerebral artery supplies the occipital lobes, and thus V1. The middle cerebral artery supplies the temporal and parietal lobes on the lateral sides, and the anterior cerebral arteries supply the frontal lobe and the central strip close to the midline. Thus, the main vascular supply to the primary visual cortex is via the posterior cerebral arteries. However, the most superficial layers of the occipital lobes may be supplied by a branch of the middle cerebral artery in some individuals. Consequently, following occlusive disease to the posterior cerebral artery, a homonymous hemianopia with macular sparing may be observed.

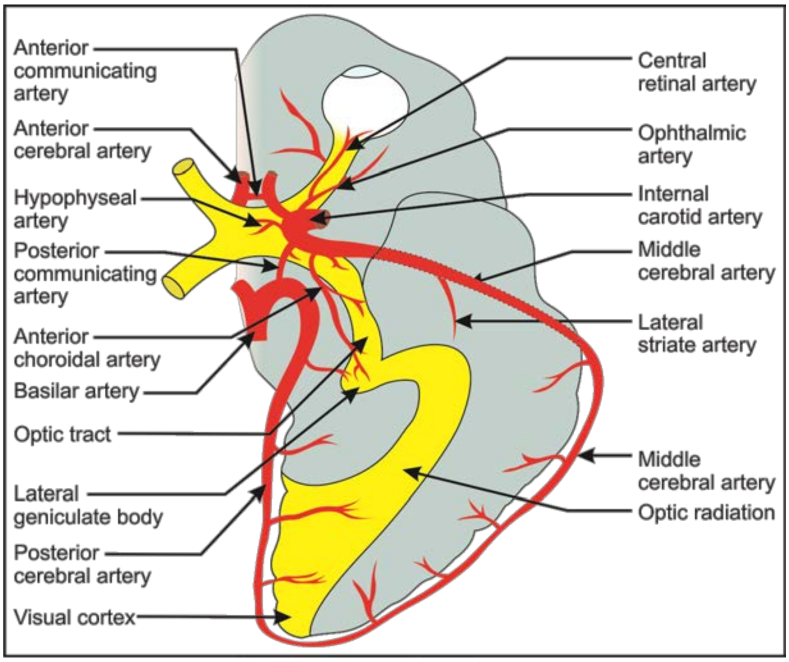

***Figure 9.13**: Blood supply to the visual areas.*